

Figure 1. Schematic diagram showing the regional plate tectonic setting of the Pacific Northwest. Cross section shows the location of the three seismic source zones: subduction, intraplate, and crustal faults. (Modified from Black and others, 2000.)

INTRODUCTION

The Interstate 5 highway (I-5) corridor, which stretches from Mexico to Canada, is both the main economic artery of the Pacific Northwest and home to the majority of Oregonians and Washingtonians. Accordingly, most regional utility and transportation systems have major components located within the I-5 corridor. For the purposes of this map, we refer to these essential systems as lifelines systems. The Pacific Northwest section of I-5, the I-5 Urban Corridor, extends from Eugene, Oregon, to the border of Canada. The population of this region is rapidly increasing with the bulk of growth and economic development centered in the cities of Eugene, Salem, and Portland, Oregon, and Olympia, Tacoma, Seattle, Everett, and Bellingham, Wash-

Lifeline Systems in Earthquake Country Economic success in the I-5 urban corridor heavily depends on critical lifeline systems, such as highways, railroads, pipelines, ports, airports, communications, and electrical power. Natural disasters that disrupt these lifeline systems can cause substantial economic losses. For example, if during a major winter windstorm, falling trees break power lines and disrupt electrical systems causing loss of power at smaller distribution substations. Subsequent widespread power outages will affect businesses and hundreds of thousands of residents. Larger scale natural disasters, such as earthquakes, present more complex challenges because they tend to affect and disable many lifeline systems at once. For example, failures in the highway system after an earthquake may make restoration of critical electrical power substations or sewer treatment plants more difficult. As a result, determining priorities and strategies for recovery becomes increasingly difficult due to the potential

simultaneous failures of several systems. As the 2001 Nisqually earthquake reminded us, Washington's Puget Sound region is earthquake country. Large-magnitude, damaging earthquakes struck Olympia in 1949 and Seattle in 1965, and the 2001 Nisqually earthquake occurred very near the epicenter of the 1949 event. In addition to these large events, smaller magnitude earthquakes are felt in the Puget Sound region about once a month. In contrast, the southern part of the I-5 urban corridor, between Eugene and Salem, Oregon, has experienced very few felt earthquakes this century. However, during the last decade earth scientists have uncovered evidence that suggests the entire I-5 urban corridor, from Eugene to Vancouver, B.C., is at risk from great off-shore subduction zone earthquakes, perhaps as great as magnitude 9.

Lifelines Systems and Earthquake Hazards

Understanding where major lifeline systems are located in relation to earthquake hazards and population centers is an important first step in developing mitigation strategies that can make the I-5 urban corridor lifeline systems more earthquake resistant and expedite economic recovery after an earthquake. Lifeline systems are complex multi-layered networks that cross through many communities and regions of varying levels of

The lifeline systems and geology shown on the map are greatly simplified. Most systems are shown in a general way for graphical purposes and may not be accurate in detail. In several locations where one system overlies another, the map symbols have been adjusted so that the systems are more distinctly visible. The surface geology also has been simplified to show regionally consistent geological characteristics throughout the entire study area of other maps in this series (Cottage Grove, Oregon, to Vancouver, British Columbia). Therefore, this map should not be used for any site-specific purpose. Any sitespecific consideration will require more detailed geotechnical and geological data than are presented in this map.

The shaded-relief base map depicts the topography over

which regional geology is draped. Individual geologic studies

(see Explanation, front of map) are compiled, generalized, and the data are categorized as areas probably less hazardous (light green) or probably more hazardous (beige) in the event of an earthquake. Simplified lifeline systems that are superimposed on the geological base and featured include: major electric power transmission lines, water supply pipelines, major sewer pipelines and treatment plants, liquid fuel pipelines, natural gas pipelines, and major ports and airports. Also shown are recent earthquakes of magnitude 2.0 and larger and historically important earthquakes estimated to be larger than magnitude 5. On this map from Woodburn, Oregon, to Centralia, Washington, crustal earthquakes greater than magnitude 5 are located near Mount St. Helens, along the St. Helens seismic zone, and near Portland.

Selected Lifelines **Powerlines** Liquid fuel Natural gas Roads Magnitudes of selected earthquakes

Figure 2. Quaternary faults and selected lifelines in the Portland area and northern Willamette Valley. Purple lines indicate faults, some discussed in text (Yeats and others, 1996; Blakely and others, 2000; U.S. Geological Survey, 2006). Power lines are shown in magenta, liquid fuel in yellow, natural gas in orange, and major roads in black (see front for all lifelines). Red circles indicate selected crustal earthquakes; purple circles indicate earthquakes deeper than 35 km. Earthquakes from PNSN catalog (www.pnsn.org). Areas of higher relative earthquake hazard in beige and lower hazard in light green.

LIFELINE SYSTEMS ON THE MAP

The map shows how the major regional lifeline systems connect with population centers. Representing highways, railroads, electrical transmission lines, and petroleum and natural gas pipelines is relatively straightforward since these systems are regional. However, representing local water and wastewater systems is more difficult because there are many local systems in the map area. With the assistance of local agencies, we selected and schematically show only the major water and wastewater systems for the four counties surrounding Portland: Washington, Clackamas, Multnomah Counties in Oregon, and Clark County in Washington. The four counties have a combined population of just under 1.8 million in 2000 (table 1), which is heavily concentrated in several cities (table 2) and in suburban centers in these counties. In all cases, the service area for water and wastewater utilities extends outside the city boundaries so that these lifeline systems serve an estimated 80

Yamhill	84,922
Washington	445,342
Clackamas	338,391
Multnomah	660,486
Columbia	43,560
Clark	345,238
Cowlitz	92,948
nd metropolitan a	in 2000 shown on areas include Was and Clark counti
	Washington Clackamas Multnomah Columbia Clark Cowlitz ation of counties and metropolitan a

percent of the population in the map area.

Washington	Cowlitz	92,94
map. The Port ington, Clacka	tland metropolitan	es in 2000 shown of areas include Was, and Clark counting,789,457.
State	City	2000 Population
Oregon	Beaverton	76,129
Oragon	Grasham	90.20

		,
Oregon	Gresham	90,203
Oregon	Hillsboro	70,189
Oregon	Portland	526,986
Oregon	Tigard	41,223
Washington	Vancouver	143,560

Table 2: Population of cities shown on map with populations greater than 40,000 in 2000.

entire population of Oregon and over 40 percent of the people living in the map area. The surface water sources are the Bull Run system in the Cascade foothills and well fields along the Columbia River near Portland. A transmission system connects the two sources with suburban users. The Tualatin Valley Water District provides water from the Portland system and surface water sources in the Coast Range to over 170,000 people living in the Portland suburbs of Washington County. In Washington, the City of Vancouver operates the fourth largest water utility in

the state, and groundwater supplies over 140,000 residents. Where digital data were available, the map shows where the rivers and reservoirs surface water sources enter the pipeline transmission systems. The map also shows the transmission system routes to their terminal reservoirs or the major distribution branches.

that discharges into the Columbia River. Major sewer lines and selected treatment facilities are shown on the map.

Electrical Power

The major electric power provider in the Pacific Northwest is the Bonneville Power Administration (BPA), which transmits the region's electricity from hydroelectric plants along the Columbia and Snake rivers to the I-5 urban corridor. BPA sells power to the major distributors in the region. Portland General Electric (PGE) is Oregon's largest utility and serves over 1,500,000 people in the greater Portland area. PGE has extensive energy generation facilities. Other large electrical utilities include Pacific Power that serves a portion of Multnomah County, Clark County Public Utilities District (PUD) and Cowlitz County PUD. Each of these distributors also has capacity to generate power. Much of the power transmitted by BPA moves through 500 kV transmission lines, and the 230 kV and 115 kV grids provide additional transmission capability.

Natural Gas

earthquake hazards. To meet the need for an integrated graphical representation of lifeline systems, geology, and earthquake hazards, the U.S. Geological Survey (USGS), in cooperation with public agencies and private companies, developed a series of maps for the I-5 urban corridor for planners, emergency response providers, elected officials, and people who live and work in this area. We divided the I-5 urban corridor from Cottage Grove, Oregon, to the U.S.- Canada border into four regions. This map covers the region from Woodburn, Oregon, to Centralia, Washington to the north and provides an overview of the lifeline systems and the corresponding earthquake hazards.

and ancient drowned forests.

are is still not well understood.

Cascadia Subduction Zone

Pacific Northwest earthquakes occur in three source

ward with respect to the North American continental plate at an

average rate of about 4 centimeters (1.5 inches) per year along

the Pacific Northwest coast (figs. 1 and 3). At the zone of

contact between the North America and Pacific Plates, the Juan

de Fuca Plate slides (or subducts) beneath the North American

continent and sinks slowly into the earth's mantle, producing the

Cascade volcanoes and earthquakes. The zone of the shallow,

east-dipping subducting plate is called the Cascadia Megathrust

Juan de Fuca Plate is absorbed by compression of the overriding

North American Plate, generally resulting in little slip on the

Cascadia Fault. However, geological evidence provided by

buried soil layers, dead trees (Atwater and Hemphill-Haley,

1997; Jacoby and others, 1997; Benson and others, 2001), and

tsunami deposits (Nelson and others, 1995; Kelsey and others,

2002) indicate that about every 500-600 years, the upper portion

of the shallowly dipping Cascadia Fault ruptures offshore and

and others, 2008). (The unit 1g is the acceleration of gravity and

is used as a measurement of the severity of earthquake ground

motion). The central Willamette Valley can expect ground

motions of about 0.2g in the areas of less hazardous geology

(light green regions on map). Shaking levels will be greater

Geologic Setting

As the Juan de Fuca Plate subducts beneath North America, it becomes denser than the surrounding mantle rocks and breaks apart under its own weight creating earthquakes

JUAN DE FUCA

GEOLOGY AND EARTHQUAKE HAZARDS within the Juan de Fuca Plate. Beneath Puget Sound, the Juan de Fuca Plate reaches a depth of 40-60 km and begins to bend even Despite the lack of recent, large, damaging earthquakes, more steeply downward, forming a "knee" (see cross section in earth scientists now understand that earthquake hazards in the fig. 1). The knee is the location where the largest intraplate zone earthquakes occur, such as the 1949 and 2001 events beneath Portland/Vancouver are greater than previously known. This may seem at odds with the experience of long-time residents of Olympia, Washington, and the 1965 event beneath the Seattle-

Oregon and Washington who can recall only the large earth-Tacoma International Airport in Seatac, Washington. The same mechanisms that cause deep earthquakes quakes farther north in Olympia, Washington, in 1949 and Seattle, Washington, in 1965; in contrast, Oregon is relatively beneath the Puget Sound in Washington may be active in quiet. The Nisqually earthquake on February 28, 2001, only Oregon. The lack of significant historic intraplate seismicity seemed to further highlight the Puget Sound area of Washington beneath western Oregon makes it difficult to assess the potential hazards. However, although there have been a few intraplate as the region more exposed to earthquake hazards. However, earthquakes beneath the Coast Range and Willamette Valley, two earthquake source regions in Oregon have drawn the attention of earth scientists: the Cascadia subduction zone and shalthere is one notable event. In 1963 a magnitude 4.6 intraplate low crustal faults. In the early 1990s, scientists reached a broad earthquake occurred northwest of Corvallis, Oregon, just south consensus that geologic evidence supports the history of great of the map area. This is the most southerly known intraplate subduction zone earthquakes of magnitude 8 to 9 that on averevent of this size in Oregon.

We do know that intraplate earthquakes have several distinctive characteristics. Because intraplate earthquakes occur at depths of 35 kilometers or more, the high frequency groundmotion energy attenuates before it reaches the earth's surface. Therefore, on rock, peak ground accelerations are expected to be about 0.2g to 0.3g, for even the very largest earthquakes. However, we note that 0.2g shaking level can cause substantial damage to poorly built structures and the shaking can be amplified in shallow, soft soils. Also, intraplate earthquakes tend to be felt over much broader areas than crustal zone earthquakes of comparable magnitude. Finally, based on earthquake studies in the Puget Sound region, significant aftershocks are not expected

zones: along the Cascadia subduction plate boundary, within the for intraplate earthquakes beneath western Oregon. subducting plate (called the intraplate or Benioff zone), and within the crust of the overlying North American Plate. Earth-Crustal Zone quakes from all three zones threaten the Portland/Vancouver The third earthquake source zone is the crust of the North The forces that produce earthquakes in western Oregon are generated as the Juan de Fuca oceanic plate moves northeast-

Fault (fig. 3). During subduction, the eastward motion of the Database, http://earthquake.usgs.gov/regional/qfaults/). How-

ever, for most of these faults, not enough is known to estimate how often the faults have ruptured during the past 10,000 years and what magnitude earthquakes could occur. Consequently, the hazards from shallow crustal earthquakes are poorly understood. Yeats and others (1996) noted that most of the mapped faults typically consist of short segments that strike either northwest or northeast. Several faults near Portland may pose significant hazards such as the Portland Hills Fault that cuts through the downtown core at the northeast edge of the Portland Hills, and the East Bank Fault that strikes parallel to the Willamette River (fig. 2). Based on aeromagnetic data, Blakely and others (2000) suggested that these two faults might connect with faults to the south. The length of this suggested fault zone could be associated with an earthquake of magnitude 7. However, no field evidence of such a large earthquake has yet been found. Blakely and others (2000) also suggested that the Gales Creek Fault west of Portland might connect to the Mt Angel Fault that

Earthquake scenarios for events as large as magnitude 6.8 on the Portland Hills Fault predict very significant damage in Portland (Wong and others, 2000), however the frequency of these events remains unknown, and there is little geologic field data in support of these events. Field investigations have found possible evidence of Holocene faulting in the Portland Hills Fault zone, but much more scientific study needs to be done before the geologic understanding allows improvements to earthquake hazard assessments. Likewise, detailed geologic investigations are needed in Clark County and along the St. Helens zone. Although farther from major population centers, the St. Helens zone is one of the most active seismic zones in Washington and has a length capable of producing an earthquake as great as magnitude 7.

NORTH AMERICA

PLATE

OREGON

NEVADA

BRITISH COLUMBIA

WASHINGTON

LIFELINE VULNERABILITY TO EARTH-QUAKES

The vulnerability of lifeline systems to earthquakes is related to the type and condition of structures and to the severity of the earthquake. Lifeline system building structures are vulnerable to earthquake shaking, just as are residential and commercial building structures. There are many types of critical structures and components that are found in lifeline systems, such as substation equipment, transmission towers, or pipelines. Damage to one of these system components may disrupt the capacity of the entire system to function.

Pipelines: Water, Wastewater, Liquid Fuel, and Natural

Buried pipelines that carry water, wastewater, natural gas, and liquid fuel can be vulnerable to damage due to surface faulting, liquefaction and lateral spreading, and landslides. Pipelines constructed of brittle materials are the most vulnerable because they are not able to bend and flex. Older, low-pressure distribution systems, such as water and natural gas, are often cast of brittle cast iron pipe. Brittle asbestos cement pipe is also used in many water systems. Pipelines constructed of relatively ductile materials such as steel and ductile iron are more resistant to earthquake-induced failure. Buried pipelines in liquefiable soils are susceptible to damage rates an order of magnitude larger than those in stable soils. If liquefaction occurs, joint restraint is also important to prevent ruptures. Modern welded joints used on gas and liquid fuel lines, and "restrained" joints used for some water pipelines are preferred in areas subject to liquefac-

Natural gas and liquid fuel pipeline systems constructed of steel and modern welded joints have performed well except in the most extreme conditions of large permanent ground displacements. Pipeline joints welded using older techniques are in some cases more brittle, and have failed. During an earthquake, it is common for many water pipelines on soft soils to fail and to quickly drain the water system. Furthermore, after a failure, water is not available for fire suppression that result from an earthquake. This scenario occurred following the 1995 Kobe, Japan, 1994 Northridge, California, 1989 Loma Prieta, California, 1923 Tokyo, Japan, and 1906 San Francisco, California, earthquakes. After the most damaging earthquakes, such as Kobe, the water service was not fully restored for more than two months. Sewer pipelines, often gravity-operated systems, are

change in grade can impair system operation. In the 1965 Seattle earthquake, a 108-inch diameter sewer was damaged when it floated upwards approximately two feet. The 1989 Loma Prieta, particularly in Santa Cruz, and the 1995 Kobe earthquakes caused similar damage. The 2001 Nisqually earthquake caused approximately 25 water pipeline failures, fewer than 10 natural gas distribution line failures, one sewer system failure, and no natural gas trans-

Earthquakes cause liquids, such as water and liquid fuels

vulnerable to flotation if the ground around them liquefies. A

mission or liquid fuel line failures.

Tanks and Reservoirs

to slosh in tanks and reservoirs. Sudden ground motion and subsequent movement of the base of a tank can load a tank wall beyond capacity. As sloshing continues, an unanchored tank can rock and break connecting piping. Furthermore, rocking can cause the tank to buckle or burst. Sloshing can also damage tank roofs and immersed components such as baffles and sludge rakes. During the Nisqually earthquake approximately 15 water tanks were damaged, none catastrophically (fig. 5). Liquid fuel tanks have been damaged and their contents caught on fire. Earthen reservoirs and dams can also be vulnerable to liquefaction and embankment failure. In Southern California, liquefaction damaged the Lower Van Norman Dam during the 1971 San Fernando earthquake, although no catastrophic water release

Electrical Power Facilities

Regional electrical power systems were out of service following the 1995 Kobe, 1994 Northridge, and 1989 Loma Prieta earthquakes. Such failures are often due to self-protecting features that are engineered into the system and can often be restored within 24 to 72 hours. Many of the power failures in the Seattle area during the 2001 Nisqually earthquake were of this

The most vulnerable components of electrical power systems typically are high voltage porcelain insulators. The higher the voltage, the larger and more vulnerable the insulator is to strong shaking. As a result, high-voltage substations, particularly 230 kV and higher, can be vulnerable to earthquake ground motion. Live tank circuit breakers, commonly used in industry, have not performed well in earthquakes. Rigid busses that connect substation equipment can transfer dynamic loads from other equipment and exacerbate insulator failures. If well anchored, lower voltage equipment functions well. Ground motions from the Nisqually earthquake were not strong enough to produce significant damage at most substations. Power poles and towers have performed well, except when they are rooted in unstable soils where landslides or liquefaction can occur. In the 1993 Landers, California, earthquake, a fault ruptured through the base of a four-legged transmission tower. The tower was distorted but it did not collapse. Ground shaking can cause low-voltage power lines to slap together causing short circuits. Higher voltage power lines have greater separation,

and thus are less prone to short circuits.

Bridges are usually the most vulnerable components of highway systems. More robust bridge design standards were developed in the 1970s and 1980s. Consequently, bridges predating the newer standards may be more prone to failure. Bridge decks can slide off their seats if the seats are too narrow or the seats are not adequately restrained. Supporting columns can buckle if they are overloaded and not designed to be adequately ductile. Single-span bridges supported on abutments perform better. Liquefaction can cause bridge foundations to move and spans they support to slide off their foundations.

The Nisqually earthquake caused significant damage to about a dozen bridges and highway structures (fig. 6), but none collapsed. In downtown Seattle, a major highway intersection at the junction of Interstate 5 and Interstate 90 was closed for several weeks for inspections and repairs. Bridge damage caused closure of northbound lanes of Interstate 5 for 12 hours in Chehalis, Washington (northern edge of map area), and the Alaska Way viaduct in Seattle was closed intermittently for weeks to assess and repair earthquake damage. In Olympia, the Deschutes Parkway was closed for weeks due to lateral spreading (fig. 7). Landslides caused closure of Washington highways

In general, railway bridges perform well because they are designed to carry very large loads. Earthquakes in the U.S. and Japan have not tested the resistance of railroad bridges to liquefaction or lateral spreading, however, but either mode of ground failure could cause loss of bridge approaches. In addition, hazards such as failed overpasses, building debris, and ground failures could affect railroad right of ways.

Airport runways may be vulnerable to liquefaction. In the 1989 Loma Prieta earthquake, 3,000 feet at the end of the main runway of the Oakland Airport were taken out of service when liquefied sand erupted through runway joints. The 2001 Nisqually earthquake caused a similar runway failure at Boeing Field where most of the largest liquefaction zones correlated with old river channels. Airport control tower glass is vulnerable, as many tower structures were not adequately designed to transfer the roof load to the structure. Control towers at both the Seattle-Tacoma International (fig. 9) and Boeing Field airports were damaged during the Nisqually earthquake.



Figure 5. Water tank anchor damage caused by the Nisqually earthquake. The anchor is about 6" in length. (Photograph by Don

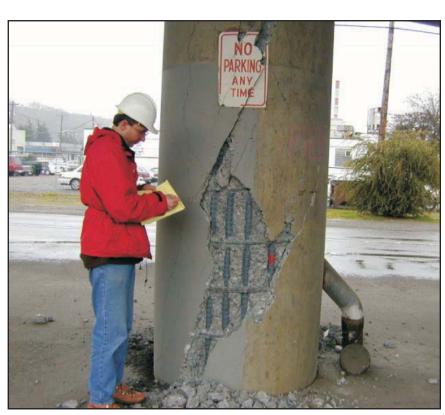
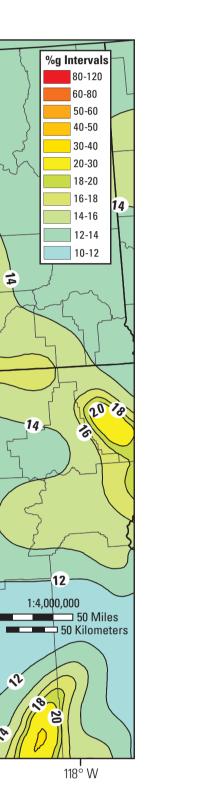


Figure 6. Short-column damage at Holgate overcrossing of Interstate 5 in Seattle caused by Nisqually earthquake. (Photograph by Mark Eberhard, University of Washington).



Figure 7. Road failure at Capital Lake in Olympia caused by liquefaction and lateral spreading. This roadway also failed in the 1949 and 1965 earthquakes. (Photograph by Steve Kramer, University of



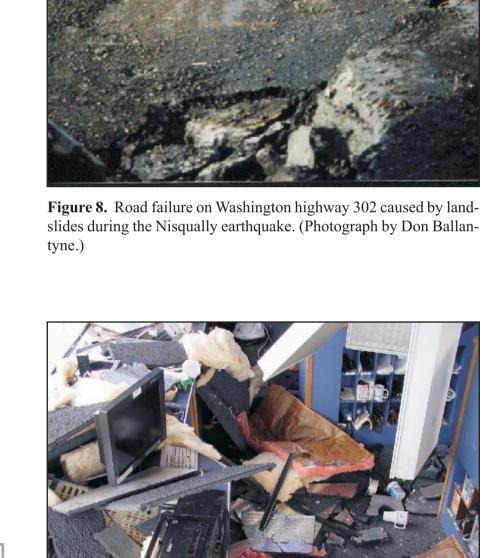


Figure 9. Control tower damage at Seattle-Tacoma International Airport caused by the Nisqually earthquake. No one was seriously injured by the debris. (Photograph by Carl Nelman, Boeing Com-

State County 2000 Population

ington, Clacka		a areas include Was a, and Clark counting, 789,457.
State	City	2000 Population
Oregon	Beaverton	76,129
Oregon	Gresham	90,203
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Oregon	Portland	526,986
Oregon	Tigard	41,223
Washington	Vancouver	143 560

The Portland Water Bureau serves almost 25 percent of the

Wastewater Four large wastewater systems in the map area serve the four urban counties surrounding Portland. The City of Portland Environmental Services operates two treatment plants that serve 660,000 people. Clean Water Services in Washington County handles wastewater for over 450,000 people. In Clackamas County the largest wastewater system is the Water Environmental Services with 150,000 customers. The wastewater for these 2001). three major treatment plants systems in Oregon is discharged into the Willamette River. The City of Vancouver system operates a wastewater system for 140,000 people in Clark County

Williams Natural Gas Pipeline Company supplies natural gas to the Portland area. Pipelines generally run parallel to I-5 north to Seattle and east along the Columbia River. Pipelines continue south of Portland to supply natural gas to the Willa-

The Portland area is served by the BP-Amoco pipeline that transports liquid fuel in a pair of pipelines (16-inch and 20-inch) from refineries in northwestern Washington south to Renton near Seattle. One line continues from Renton to serve Portland. The BP-Amoco pipeline connects to a steel, 8-inch diameter liquid fuel line operated by Kinder Morgan Energy Partners that provides liquid fuel to the southern Willamette Valley.

Traffic volume along the I-5 urban corridor ranges beween 25,000 vehicles per day near Cottage Grove south of Eugene to over 150,000 per day in southern Portland. Traffic across the Interstate Bridge over the Columbia River is 120,000 vehicles per day, including about 10,600 trucks (Oregon Dept of Transportation, 2002). Traffic on I-5 decreases to about 50,000 vehicles per day north of Vancouver and downtown Portland sees another 100,000 vehicles per day on I-405. East of Portland, traffic counts vary from about 88,000 to over 150,000 per day, and 132,000 vehicles cross the Columbia River. West of Portland, Oregon Route 217 accommodates over 100,000 vehicles per day between the junctions with I-5 and U.S. 26. Oregon Route 8, an important non-freeway connection west of Portland, serves over 40,000 vehicles per day.

Several major east-west highways serve Portland. The main link is I-84, with as many as 180,000 vehicles per day in the downtown Portland area. Farther east, near the map edge, counts on I-84 drop to about 20,000 vehicles per day. West of Portland, along the Columbia River, traffic counts range from about 48,000 vehicles per day in the city to less than 10,000 near the map edge. On U.S. 26, traffic decreases from 60,000 vehicles per day in Portland at I-5 to about 12,000 to the east. At the intersection of I-405 and U.S. 26 in Portland, traffic counts are 140,000 vehicles per day and decrease below 10,000 along

U.S. 26 in the Coast Range. Along State Route 4, which connects Kelso, Washington, to coast, traffic is about 28,000 vehicles daily at I-5 and decreases to less than 2,000 at the western edge of the map area. At the north edge of the map area, about 6,000 vehicles use U.S. 12 daily. Finally, State Route 14 serves approximately 50,000 vehicles per day near the I-5 junction and decreases to about 5,000 vehicles to the east. Truck traffic on I-5 is extremely important to the regional economy. In a study of 17 western states, including heavily

populated Texas and California, the Seattle-to-Portland section of I-5 ranks first in truck tonnage. The Portland-to-Eugene section of I-5 ranks second in tonnage and ranks fourth in total numbers (Oregon Dept of Transportation, 2000).

Railroads The Union Pacific and Burlington Northern Santa Fe (BNSF) are the two mainline railroads that operate in the greater Portland area and provide north-south freight service to Portland, and tracks on both sides of the Columbia River connect the urban corridor with eastern markets. The rail lines through the Columbia River Gorge are by far the most heavily used tracks in the Pacific Northwest (Oregon Dept of Transportation, 2001). Major railroad bridges cross the Columbia and Willamette Rivers. Seventy freight and ten passenger trains cross the Columbia River Bridge every day. The Portland area is home to intermodal terminals that handle large volumes of freight. In 1999, the BNSF terminal in north Portland generated 1,000 truck transports every day (Oregon Dept of Transportation,

The Port of Tillamook Bay (POTB) and the Pacific and Western (P & W) are the two main short line railroads in the map area. The POTB lines run west from Portland to Tillamook Bay, whereas the P & W lines run south to the Willamette Valley and northwest to Astoria. Six passenger trains operate daily from Portland heading south and ten passenger trains connect north to Seattle. A light rail system operates in the Portland

Portland International Airport is the second largest commercial airport in Oregon and Washington and is the 30th largest in the United States. The airport serves over 12,000,000 passengers and handles 250,000 tons of air cargo. The largest general aviation airport in the map area is the Hillsboro Airport, west of Portland.

The Port of Portland, located along the Columbia and Willamette Rivers, is the eighth largest United States port in terms of total tonnage and is the fourteenth largest in terms of container cargo. The port is the nation's second largest exporter of wheat and is the largest importer of automobiles. Other key port facilities in the map area are located in Vancouver, Kalama, and Longview, Washington.

Earthquake Distribution

43°N _

PACIFIC

PLATE

GORDA

PLATE

200 Kilometers

portion of the Juan de Fuca Plate, purple.

The Cascadia subduction region stretches the length of the

Pacific Northwest coastline, so it is useful to consider the distribution of earthquakes across the entire plate boundary system and examine the regional picture formed by integrating all three earthquake source zones. Compared with earthquakes in the intraplate zone, crustal events are much more widespread, occurring over much of northwestern California and most of Washington. However, figure 3 shows that there are relatively few earthquakes in Oregon and that the Willamette Valley is particularly quiet. In spite of the fact that scientists know from field studies that subduction events are possible, there are no recent Cascadia zone earthquakes that have been located in Oregon. Thus, in the absence of recent significant seismic data, figure 3 illustrates the importance of conducting more detailed geological field studies and examining evidence of historical earthquakes in order to link recent earthquakes to faults and better understand and assess the potential for future significant earthquake occurrences in the greater Portland/Vancouver

Probabilistic Ground Motion Map A useful representation of earthquake shaking hazards is a probabilistic seismic hazard map. Based on local geologic and seismic data, the USGS has developed probabilistic seismic hazard maps for the entire country (Frankel and others, 1996; 2002; Peterson and others, 2008, and see http://earthquake. usgs.gov/research/hazmaps/). These seismic hazard maps underpin seismic building codes and many highway construction standards. The probabilistic hazard map (fig. 4) shows the expected peak horizontal ground motions on a rock site with a 2 percent probability of being exceeded within a time frame of 50 years. Figure 4 includes all three potential earthquake sources for the Northwest: subduction zone, intraplate zone, and crustal faults. Along the Oregon Coast, the seismic hazard is dominated by the north-south Cascadia subduction zone. Moving eastward, the Greater Portland/Vancouver area, the inland contours broaden reflecting increased rates of seismicity in the northern Oregon Cascade Range (fig. 3) and along the St. Helens seismic zone (figs. 2 and 3). Farther north, the eastward bulge of the contours indicates higher expected ground motions in the Seattle area and reflects the high rate of large-magnitude intraplate earthquakes in this region. The east-west oval contour indicates the relatively higher hazard potential in central Puget Sound region and also reflects current scientific understanding of the Seattle Fault. This illustrates how increasing the detailed geologic knowledge of an individual fault may change hazard assessment. For example,

an area of higher hazard potential around the Seattle Fault was

indicated in recently updated maps because field and seismic

studies demonstrated that large (M 7.0) earthquakes occurred on

the Seattle Fault in the past. Geologic studies in western Oregon

are in progress to examine faults and update the regional seismic hazard assessments.

Earthquake Hazards

CALIFORNIA

Figure 3. Known earthquakes in Cascadia greater than magnitude 6 since about 1870, magnitude 5 since

1950, and earthquakes of magnitude 2 and greater located by the modern seismographic networks and

catalogued by the University of Washington (www.ess.washington.edu). Earthquakes are grouped into

two broad zones: shallow crustal earthquakes, red; earthquakes in the intraplate zone and the shallow

Even though there is considerable uncertainty as to how often earthquakes may hit the Portland/Vancouver region, it is possible to evaluate and improve estimates of potential earthquake damage. Ground shaking occurs in a wide area following an earthquake. Because of the complexity of the three source zones, it is useful to implement the probabilistic hazard map (fig. 4) as an initial guide to determine areas of strong shaking. However, unconsolidated young deposits often amplify low to moderate ground motions, sometimes by a factor of two or more. Poorly consolidated soils are typically found in river and stream valleys and areas of artificial fill. The detailed maps prepared by Oregon Department of Geology and Mineral Industries (DOGAMI) discuss key factors affecting amplification (see for instance Madin and Wang, 2000). Therefore, areas of young, unconsolidated deposits (beige on map) are considered more susceptible to intense ground motions than areas of rock or well-consolidated sediments (light green on map) sites. Significant sections of the lifeline systems in the river valleys of the Portland/Vancouver region traverse areas of unconsolidated materials that may amplify ground motions.

Generally, many of the same areas subject to amplified ground shaking are also susceptible to liquefaction. In areas of unconsolidated, young deposits (beige on map), strong shaking can increase pore pressure within water-saturated soil causing the soil to lose shear strength, or liquefy, and lose the ability to support large loads, such as buildings and roads. In areas adjacent to a riverbank, or on a slope, lateral ground motion can move and disrupt buried pipelines and foundations. Thus, the beige-shaded areas that are susceptible to liquefaction carry additional hazard significance.

Steep slopes can produce landslides during earthquakes. An important lesson for the Portland/Vancouver region from the large earthquakes in Puget Sound area is that not all landslides occur in the first few minutes following an earthquake but can occur days later. In 1949, a large landslide near Tacoma, Washington, slipped 3 days after the earthquake. Steep slopes along the edges of the Willamette Valley and southern Washington, often near saturated conditions because of high rainfall, are candidates for earthquake-induced failure, though we have not delineated these areas on this map. As earth scientists improve their understanding of crustal fault behavior in the Portland/Vancouver region, it is possible that fault surface rupture may become a concern. In the Seattle, Washington, area, recent discovery of young faults breaking at

the surface has identified a fault zone in central Puget Sound

where surface rupture could occur. Although for any given

earthquake the chances of surface rupture may be small, it may

be appropriate to consider such a possibility.

ABOUT THE MAP

30-meter digital elevation model (DEM). Shorelines and streams originate from USGS digital line graphs (DLG) derived from 1:100,000-scale maps (see http://edc.usgs.gov/geodata). This map is based on material originally published in U.S. Geological Survey Open-File Report 99-387 (Haugerud, and others,

Earthquakes and Geologic Units on the Map

Earthquakes recorded and located since 1969 by the Pacific Northwest Seismic Network (http://www.pnsn.org) are shown on the map and range in magnitude between 2.0 to 5.7. The earthquakes are divided into shallow, crustal earthquakes (< 35 km) shown in red and earthquakes with epicenters deeper than 35 km shown in purple. There have been very few earthquakes located or detected in the Portland/Vancouver region. Most of the events are located in the northeastern portion of the map and are located along the St. Helens Seismic Zone, the most shallow, seismically active area in Washington, or beneath Mount St. Helens, which reflect volcanic processes at volcano. To the north, the 1981 Elk Lake earthquake, magnitude 5.5, is the largest earthquake in the map area. Two other notable earthquakes are the 1961 magnitude 5.1 Siouxon Peak earthquake located along the St. Helens Seismic Zone and the 1962 magnitude 5.2 earthquake located near Portland and Van-

into two basic units reflecting relative seismic hazard: 1) young, unconsolidated deposits and 2) consolidated deposits. Beige colors represent predominantly young, unconsolidated fluvial and alluvial deposits, which are susceptible to liquefaction, ground amplification, and/or landslides triggered by an earthquake. Light green represents bedrock and older, wellconsolidated surface rocks and deposits considered to be less subject to earthquake-related liquefaction, amplification, or landslides. Generally, hilly areas adjacent to the valley floor are considered less prone to earthquake hazards and are categorized as seismically less hazardous (light green on map) areas. The exception is hilly areas prone to landsliding (beige on map). The valley floors are typically covered by younger and lessconsolidated surface deposits and are therefore categorized as more susceptible to earthquake hazards (beige). The beige and light green categories are determined solely on descriptive geologic information and did not incorporate engineering analyses. Geologists working on this project reached a consensus on which mapped geologic units should be placed into each category of relative earthquake hazard, and this map follows previous study guidelines (Wang and Leonard, 1996; Mabey and others, 1997; Madin and others, 2000a-b; Palmer and others, 2004; Burns and others, 2008). We compiled geological information from several data sources (Walker and McLeod, 1991; Mabey and others, 1994; Mabey and others, 1997; Madin and others, 2000a-b; Hofmeister and others, 2003: Palmer and others, 2003; Palmer and others, 2004; Burns and others, 2008) and the geologic background reflects prioritizing the most recent studies and highest resolution data based on map scale. Compiling and layering of different geologic sources into the map geologic background occasionally result in abrupt artificial boundaries due to data source boundaries. Please refer to references and the legend inset map for more details.

earthquake, the very near surface units of the Washington NEHRP map (Palmer and others, 2004) data are divided into units ranging from hard rock to soft soils. The boundary between stiff soils and very dense soil/soft rock (NEHRP values D/C) is categorized in this map as the distinction between higher (beige on map) or lower (light green on map) soil susceptibility to amplification during an earthquake (Palmer and The highest resolution data (1:62,500 to 1:24,000 scale) are simplified from recent Oregon Department of Geology and

ment of Natural Resources reports, referred to as Interpretive Map Series (IMS) and Geologic Map Series (GMS) (Mabey and others, 1994; Mabey and others, 1997; Madin and others, 2000a-b; Hofmeister and others, 2003; Burns and others, 2008). Data from the IMS and GMS studies constitute the top layer of geologic data on this map. These studies characterize sites based on soil and rock susceptibility to amplification, liquefaction and landsliding during and earthquake. Wang and others (1998) and Wang and Madin (2001) describe the integration of the three site response components into six relative earthquake hazard zones, A through F. Types A-C are lower relative earthquake hazard (light green on this map) categories, and D-F are soils that are considered higher relative earthquake hazard category (beige on this map). Units characterized as 'high' or 'very high' hazard susceptibility to amplification, liquefaction and landsliding during and earthquake in reports by Burns and others (2008) and Hofmeister and others (2003) are designated higher earthquake hazard (beige) on this map. Communities included in the map area that have completed relative earthquake hazard maps are shown in the inset map of the Explana

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MORE INFORMATION

There are many good sources for more information concerning earthquakes and the effects of earthquakes in the Portland/Vancouver region. The Oregon Department of Geology and Mineral Industries (http://www.oregongeology.com) and Washington State Department of Natural Resources (http://www.dnr.wa.gov) provide information on evaluating earthquake issues. Oregon Emergency Management (http://www.doc.state.or.us/OMD/OEM/index.shtml) and Washington Emergency Management Division (http://www.emd.wa.gov/hazards/haz_index.shtml) provide information available regarding earthquake response and mitigation. All of these sites have many links to other resources. Current earthquake activity is available at the Pacific Northwest Seismic Network site, http://www.pnsn.org. Complete details for national seismic hazard maps can be found at the following USGS site: http://earthquake.usgs.gov/research/hazmaps/. The Federal Emergency Management Agency maintains a long list of

materials related to earthquake preparedness, mitigation, and

response planning (www.fema.gov). The American Red Cross

has details on personal preparedness (www.redcross.org). The

Cascadia Region Earthquake Workgroup (www.crew.org) is

regional private-public partnership dedicated to increasing

earthquake mitigation efforts in the Pacific Northwest.

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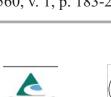








1 map sheet, scale 1:62,500.









westward toward the coast (fig. 4); 2) Strong shaking that can last for two to four minutes as the earthquake propagates along the fault and long-period seismic waves that can affect very tall structures and high bridges; 3) Shaking effects that can significantly damage the regional lifeline systems in all of Cascadia's major population centers, from Vancouver, B.C., to Eugene, Oregon. 4) Tsunamis that are generated by sudden uplift of the sea floor above the Cascadia Fault. Effects of past tsunamis have recently been mapped and include marine sediments deposited inland

Intraplate Zone

age strike the Oregon coast every 500-600 years and shake the western interior of the state. In addition, earth scientists are beginning to develop an understanding of shallow faults near the earth's surface that may further influence earthquake hazard assessments for this part of the I-5 urban corridor. In northern Oregon and southern Washington, a number of crustal faults are mapped in the Portland area (fig. 2), but how active these faults

American Plate. Crustal zone earthquakes are typically small magnitudes (and usually are not felt), relative to subduction zone earthquakes, and they are the most common earthquakes in western Oregon and southwestern Washington. The magnitude 5.5 Elk Lake earthquake in 1981 (map and fig. 2) is the largest known North American Plate earthquake in the map area (the magnitude 5.6 1993 Scotts Mills earthquake occurred just to the south of the map area). There are two other events greater than magnitude 5 on the map: the 1961 magnitude 5.1 event at Siouxon Peak is located along the southern extension of the St. Helens Seismic Zone, and the 1962 magnitude 5.2 Portland earthquake is located just north of the Columbia River in Clark County, Washington. Most of the larger events plotted in figure 2 are concentrated along the St. Helens seismic zone directly beneath Mount St. Helens and are related to volcanic processes There are many mapped faults in the greater Portland area thought to be active during the Quaternary, or last two million years (fig. 2; and see U.S. Geological Survey Quaternary Fault

produced a magnitude 5.6 in 1993 (fig. 2).

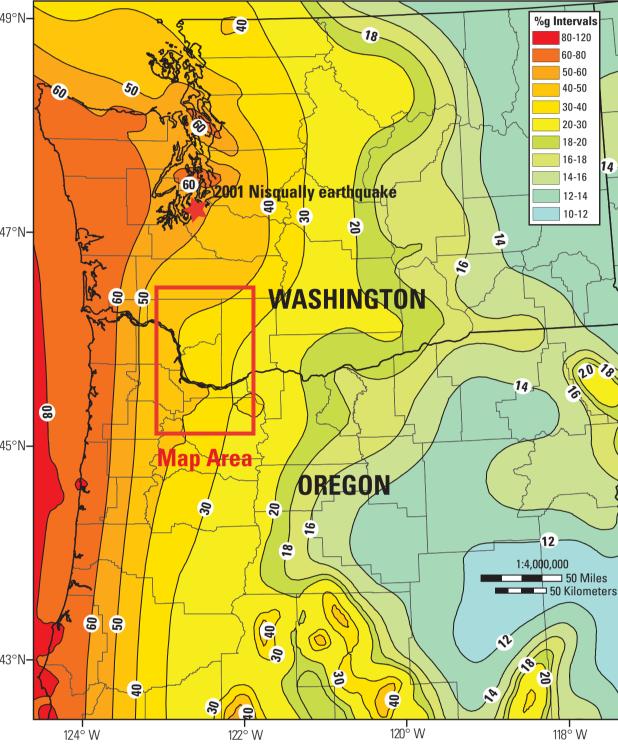


Figure 4. 2008 probabilistic seismic hazard map for portions of Oregon and Washington. The map shows the ground motions (%g) with a 2% probability of being exceeded in 50 years. Details are given in Frankel and others (1996; 2002), Peterson and others (2008), and

The base map was derived from a U.S. Geological Survey

at http://earthquake.usgs.gov/research/hazmaps/.

The geologic units in the map area have been simplified

The lowest resolution data compose the background geology of the map and are based on the 1:500,000 scale Oregon geology map developed by Walker and McLeod (1991) and the 1:100,000 scale Washington National Earthquake Hazards Reduction Program (NEHRP) map (Palmer and others, 2004). Young, unconsolidated sediments of the Walker and McLeod (1991) map, such as alluvial and fluvial sands and gravels and some older marine sedimentary rocks, are considered to be more susceptible to ground motions during an earthquake (beige on map). Based on response to ground shaking during an

Mineral Industries (DOGAMI) and Washington State Depart-

Earthquake Hazards and Lifelines in the Interstate 5 Urban Corridor: